The following is a re-formatted pair of documents, the first is the document the author wrote early in 1972 and sent to NASA for consideration (naively) and followed by the reply received from NASA in mid-1972. The author believed it would make a fine follow-up space project after the Apollo project, which was nearing its conclusion at the time.

THE MOONCABLE: A PROFITABLE SPACE TRANSPORTATION SYSTEM

March 25, 1972

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Abstract

The theoretical basis and major engineering concepts of a unique space transportation system are being presented. It is intended primarily for bringing Lunar and space-environment commercial products to Earth at potentially very low expense on a long-term, high mass payload, continuous operation basis. Viewing, the moon and Earth as two adjacent, partially merging gravitational pits in space, a tensile structural attachment to the Lunar surface is constructed in the saddle between the two pits of such dimensions as to remain in place supported by the upper part of Earth's gravitational pit. Masses descending down the tensile structure, or cable, into the Earth's pit are slowed by electromagnetic braking against the cable, exchanging gravitational energy into electrical energy. The electrical energy is transferred to a conductor system on the cable, which is preferable superconducting by use of sun ward layered foil reflectors. The conductors carry the electrical energy across the gravitational hump to the moon-ward part of the cable, where electromagnetic traction motors exchange the electrical energy back into gravitational energy, lifting payload up from the Moon. The strength limitations of existing engineering materials are overcome by the creation of a constant-tensile-stress concept, which makes all parts of the structure carry an equal load by appropriately varying its cross-sectional area along its length. To show that it can be done, an example cross-sectional distribution has been worked out for a cable of 10E4 lbf lifting capacity from the Moon's surface, requiring a maximum area of 21 in2 at the zero-acceleration point between the two pits, and shrinking to one-hundredth that area at the point of contact with the Lunar surface. The structural material used in the example is silica fiberglass, due to the abundance of silica on the Lunar surface, and assumes a strength of 5E5 lbf and a safety factor of 2. The emplacement of the resulting large mass of cable is made feasible by the concept of a "growing" cable, starting from a "seed" filament brought from Earth, and progressively increased in area by electrically raising new fiberglass up from an expanding fiberglass manufacturing automatic plant on the Moon, ever-increasing the lifting capacity of the cable. The initial fiberglass- producing plant landed there probably would be between the size of Surveyor and Apollo.

With the efficiency allowed by using superconductors, the Mooncable theoretically can transport payload from Luna to Earth at zero energy cost, and actually may be able to provide a surplus of electrical energy during this transportation process, depending on the length of the cable. Initial Lunar and space environment products for import to Earth markets involve zero-g foamed-steel and foamed ceramics cast into glider shapes with cargo compartments to be dropped off the end of the "Mooncable" into Earth's atmosphere.

The structural mass of very large spacecraft for extensive space exploration, made of Lunar materials, can be lifted up out of the Moon's gravitational pit at an estimated 3 cents per pound, using externally supplied electrical energy from a small nuclear-electric powerplant on the Moon or on the cable for this function.

Purpose

The purpose of this document is to disclose the fundamental concepts of a unique category of transportation in space, which may enable our declining space industry to revive by creating a system continuously transporting large quantities of Lunar environment products to Earth markets at negligible cost.

This document will be limited to a brief presentation of the fundamental transportation concept along with one set of engineering concepts which might be used to implement the system.

Materials and other products from the unique space and Lunar environments, such as "foamed steel" would be marketable profitably if the cost of bringing them to Earth markets were sufficiently reduced. Foamed steel is expected to be a building construction material of outstanding usefulness.

Chemically-fueled fueled rocket propulsion transportation, such as used by the Apollo project, is too inefficient to provide inexpensive transportation to market, because nearly all of the fuel energy is used just to lift the fuel mass itself.

An alternative Lunar-Earth transportation system concept is now being proposed, which potentially can reduce the transportation energy cost to a negligible expense, although some of the features of the concept stagger the imagination. No chemical energy fuels need be brought from the Earth to the Moon, or be made on the Moon. It is necessary to the understanding of the concept to change one's visualization of what lies between Moon and Earth. Analogously imagine a small model of two adjacent pits in the ground, the shallower one containing water. Then note that the water from the shallower pit may be siphoned into the deeper one without addition of external energy, provided that a hose is provided and the siphoning process is started. Such a siphoning process will power itself provided that the work applied to the mass being transferred down the deeper slope is greater than the work required to lift the mass up from the shallower side. The Earth and its moon, Luna, may be pictured as two adjacent gravity pits in space, the pit corresponding the the Moon being much less deep than that of the Earth.

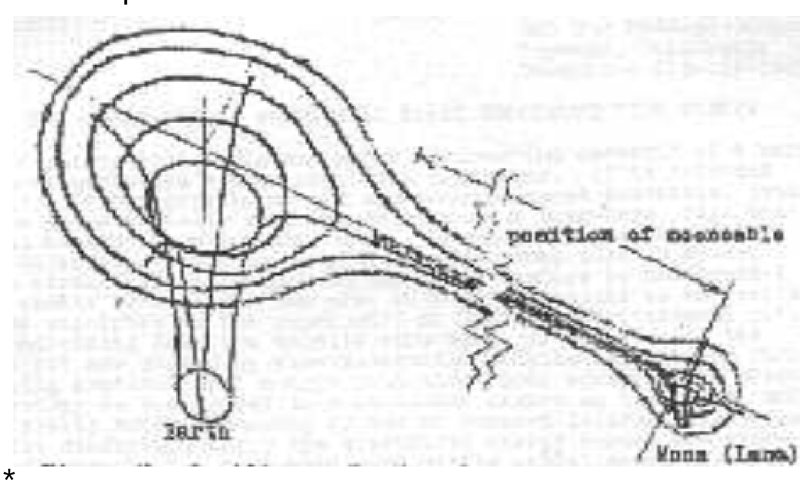

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Figure No. 1:
Adjacent Earth and Moon Gravitational Pits

The total work of lifting mass from R0 to R is the area under the curve representing the force of gravitational attraction,

$$W = \int_{R_0}^{R} \frac{GMm}{r^2} dr = GMm\left(\frac{1}{R_0} - \frac{1}{R}\right)$$

The work involved in getting in or out of the Moon's gravity pit is 2.9E6 joule per kg, or 807 watt-hours per Kg. Similarly, the work energy received going down Earth's gravity pit is 6.2E7 joule per kg, or 17.3 KW-hr per Kg. Also, in going from the Moon to Earth an orbital kinetic energy of 140 wHr must be given up. The resulting algebraic sum of energy is 16.5 KW-hr per Kg surplus energy. Therefore, a siphon-like process could continuously move Moon-mass payload to Earth without further input of energy, theoretically.

A siphon-like process can analogously be formed by a continuous balancing interchange of electrical energy and gravitational energy between masses going up and down gravitational slopes. Electrical energy can be converted into gravitational energy such as by an electric traction motor powering an attached payload up a cable; gravitational energy is converted to electrical energy by a payload pushing a traction-coupled electric generator down a cable; and electric power is coupled between up- and down-moving masses by electrically conducting tracks along the cable.

A cable, or other tension structure, if it is attached to the Moon's surface and extends up out of the Moon's gravity pit toward Earth far enough so that part of it hangs down part way into Earth's gravity pit, will stay there in place without external energy applied, if the weight of the part of the cable in Earth's pit is at least as great as the weight in the Moon's pit.

A constant cross-section tension structure, such as a common rope or cable, must have a tensile strength-to-density ratio which excludes most known engineering materials. However, a "constant-tensile-stress" structure concept produces a varying cross-section cable which easily has sufficient strength for this purpose, being larger in cross-section where tension is greater in the cable.

This tension is greatest at the point where the Moon-Earth gravitational accelerations with the angular centrifugal acceleration cancel out one another, and is less than the tension bearing the weight of an infinitely long cable extending out from the Moon's surface.

To prove that a constant-cross-section cable can be strong enough for this purpose, an imaginary cable extending from the Moon to infinity was divided into sections of constant-crossection area, the area of each section being that required to support the weight of that section plus the weight of the cable below it plus the attached conductor weight and live loads, expressed by the following equation:

$$F_{n+1} = (A)(S) = \frac{(F_n)(S)}{(S) - (d)(r_0)(\frac{1}{6g})\int_{r_n}^{r_{n+1}} \frac{1}{r^2} dr}$$

Where Fn = Force atop a section of cable
Fn+1 = Force atop next higher section of cable
S = working tensile stress of cable material
d = density of tensile material
r0 = radius of planet or moon

An outside figure for the mass of an example rope was determined by applying the above equation in 23 cable sections to find the maximum required cross-sectional area at infinity. The assumptions were:

(a) A maximum upward pull on the Moon by the rope of 2.5 X 10E4lbf (1.1 X 10E5 newtons)
(b) A niobium-copper superconductor constant-cross-section equal to a pair of #12 wires,
(c) A maximum live load force lifting an object from the moon of 10E4 lbf (4.4E4 newtons)
(d) A density of 8.3E-2 lbm/in3 fiberglass
(e) A working tensile stress in the fiberglass of 2.5E5 lbf/in 2 which assumes a strength of 5E5 lbf/in 2 and a safety factor of 2.

The resulting cross-sectional distribution is shown in figure 2.

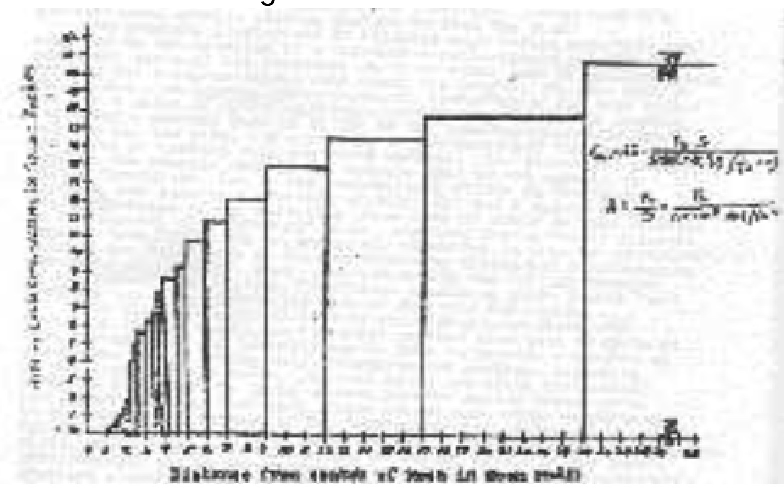

Figure No. 2:
Cross-sectional area distribution of approximated "constant- tensile-stress" cable extending to infinity, and having an input load of 2.5X104 lbf pull on the moon

The length of the cable will be less than that distance between Moon and Earth, 3.8E5 Km; and the average area will be less than that of the maximum if at infinity, which is 21 in2 (1.3E-2 m2). With a glass specific gravity of 2.3, this makes a mass of 2.6E9 lbm.

Raising this mass from the moon is made reasonable by using a special construction technique of using an initial filament brought from Earth and emplaced by chemical rocket transportation. This filament is gradually built up exponentially in dimensions and strength by electrically raising the fiber being added as it is made by an appropriately growing glass manufacturing plant on the Moon. Earth-launch mass of the "seed" fiberglass filament, starting with two strands at the Moon's surface, is 2.5E4 lbm if 5E-4 inch diameter fibers are used, or 4.4E3 lbm if 1.5E-4 in diameter fibers are used. This does not include weight of reels, control equipment, and auxiliary equipment.

Assuming nuclear-electric energy at the Moon at a long term average cost of 10c per KW-hr, the energy cost of raising this rope's or cable's mass is less than 10E9 KW-hr, or 10E8 dollars, assuming also that the conductor is superconducting at the major phases of construction, and that generator efficiency is 99%, and an average electric traction motor efficiency of 91%.

The fiberglass is manufactured from the silica so plentiful on the Moon"s surface, making it the ideal cable material. Heat energy needed to melt it may come from solar reflectors. Mechanical energy needed to form the fibers may come from the use of solar energy being used to expand a gas, or from the nuclear-electric powerplant. The size of the initial glass plant accompanying the emplacement of the "seed" fiber filament cable may be similar to that of the Surveyor spacecraft which were soft-landed on the Moon many years ago. Earth-made parts for later larger glass manufacturing facilities would use the partly-built rope or cable to reduce the cost of transportation to the Moon. The manufacture of strong fiberglass filaments would be greatly assisted by the vacuum so plentiful on the Moon, since contact with air reduces fiberglass strength during manufacture on earth. Space-rated fiberglass rope was for

sale several years ago with a strength of 5E5 lbf/in2 so a working tensile stress in the rope of 2.5E5 lbf/in2 was used in the preceding example rope calculations, using a safety factor of 2, which is very conservative compared with a safety factor of 1.6 normally used in construction practice. The total mass of the rope needed would go down rapidly when the working tensile stress allowed is increased. Glass fibers drawn and baked in a vacuum have been measured as strong as 1.8E6 lbf/in2, so there is a good possibility that, for a given maximum payload lifted, the size of the cable may be greatly reduced over the "outside" value determined in the example calculation.

The area of the mooncable's cross-section would best be distributed in the form of a net or thin hollow tube, to prevent the cable from being completely severed by smaller hurtling objects. The conductors would best be distributed around the tensile supporting structure for the same reason, allowing continuous power for repair activities, and for bidirectional traffic during normal use of the system. A widely distributed cross-section would also help in case the mooncable was ever severed, helping increase the amount of atmosphere which dissipates the falling cable's mass energy.

The Conductor and Motor Types

The conductors would need to be superconducting to enable the energy balance equations to approach reasonable accuracy, avoiding resistance heating losses in the conductor. Multiple layers of reflecting, insulating foils kept on the solar side of the rope may be sufficient to allow radiation losses to adequately cool the superconductors. The conductors might be still further cooled by having each tractor spray the conductor with cryogenic liquids from "lunar cryostats" during each passage along the rope.

The configuration of the conductors might be in the form of linear stripes for rolling or wiping electrical contacts to drive conventional traction motors, or spiral for use in a linear electric motor system. Direct current is assumed to be used, as the hysteresis loop in hard superconductors prevent the use of alternating currents and linear induction motors. If the conductors are difficult to cool sufficiently to be superconducting, energy losses would need to be minimized by using high voltages between conductors. A-C linear induction motors or conventional electric track propulsion concepts apply during the climb up the cable, with conversion of the motors to generators during the fall down the other end of the cable. Additional electrical energy might need to be supplied from nuclear-electric or solar-electric powerplants along the rope or on the Lunar surface, to overcome conductor resistance losses. This would still be high-efficiency transportation, requiring no chemical energy fuels to be made on the Moon, or to be brought from Earth.

Application of the System

The path from the Moon to the Earth is interrupted by the gap from the end of the mooncable to the surface of the Earth, so one way of bridging the gap is to modify the form of the larger imported products, such as the foamed materials, into shapes that can independently survive the drop into Earth's atmosphere and landing. For example, the importation of "foamed steel" might be made possible by lifting Lunar siderite steel up the cable to the zero acceleration point where it would be melted in a solar- reflector furnace and foamed into a mold which casts it into the shape of a giant low-density glider which then continues along the cable to Earth-end, where it drops off it into Earth's atmosphere into the ocean where it would float until collected, or glided under control to more accurately determined market sites for delivery to foamed-steel purchasers or conventional steel producers around the world. This steel operation alone may be able to support an expanding space industry, with the other space environment products being extra value. The "mooncable" also could lift the bulk of immense spacecraft, made of lunar materials, to the zero-g potential point on the cable for assembly and launching toward ambitious space exploration efforts such as a manned landing on Mars or collection of gasses from Jupiter's

atmosphere, and perhaps an exploratory trip to a nearer star.

(Incidentally, Mars' two moons Phobos or Deimos could be used in a similar way in bidirectional transportation between Mars and points distant from its concentrated gravity field by electrically powering elevators operating between moon orbit altitudes and several miles above Mars' atmosphere, although a running start of about 1000 mph would be necessary to catch the end of a rope attached to Phobos, and much less if attached to the more distant Deimos.)

Summary

This document has presented a concept of a new category in space transportation, along with some of the engineering concepts which could be applied to implement and use the transportation system. The ideas contained herein are hoped to be both the starting point and the goals for the labors required of the many talented and imaginative people who are needed to make the transportation system a reality. But it can be made a real, working, and useful system only if the people who create it are determined to make it work.

Author's notes:

Figure 2 shows the graphed values of several months of calculations made in spare time, with only slide rule, pen and paper. Although desk calculators and even a pocket scientific calculator, the HP35, existed in that time, none of these were available to the author at the time. There was a mathematical error made, obvious when graphed in figure 2, made at about 2 lunar radii; but since the purpose of the document was to show that a real and plausible value for maximum cross-section of the space-rated fiberglass Mooncable did exist, and since the error merely made the cross-section look even larger than the accurate value, the months of tedious hand calculations were not repeated, since the purpose of the calculations were fulfilled.

The above reformatting was done in Appleworks on 2003 04 11 by J E D Cline, using the earlier reformatting done for the home.earthlink.net/~jedcline/ website in 1998.

James E.D. Cline

(NASA's Reply to Mooncable Follows. This is the response made by NASA's Invention and Contribution Board in response to the early effort to create a Mooncable Project. James E. D. Cline)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D. C. 20546
Reply to attn of: KB

June 23, 1972
Mr. James E. D. Cline
905 Old Topanga Canyon Road
Topanga, California 90290

Dear Mr. Cline:

Your letter of June 3, 1972, which was addressed to Dr. George M. Low, Deputy

Administrator of the National Aeronautics and Space Administration and which briefly described your concept entitled "The Mooncable: Gravitational-Electric Siphon in Space", was referred to the Inventions and Contributions Board for review and reply. We are also in receipt of related correspondence and a document entitled "The Mooncable: A Profitable Space Transportation System", which was forwarded to this office by Mr. Monte Mott, Patent Counsel of the NASA Pasadena Office. A review has now been completed of all of your material that has been received, and we should like to provide you with the following explanatory comments and suggestions.

The proposal which you have outlined in your correspondence is obviously conceptual in nature, and describes a project which, if undertaken, would involve a significant expenditure of time and money to transport materials from the lunar surface to the earth. For your information, the lunar landing of the Apollo 17 mission which is now scheduled to take place in December, 1972, will conclude NASA's program to investigate the lunar surface, at least so far as the immediate future is concerned. Following termination of the Apollo program, we shall move on during the remainder of this decade to the Skylab program and subsequently, to the Space Shuttle program. You will find enclosed a copy of NASA EP-81 entitled: Man in Space (Space in the Seventies), which explains how NASA plans to accomplish the objectives of these programs. Present and future budgetary commitments to attain the goals outlined in this booklet will not permit the consideration of expenditures for extensive new projects such as the one you have submitted, and we are therefore not able to make a favorable recommendation with respect to your proposal. In your letter to Dr. Low, we inferred that you were requesting that NASA contribute funds for the promotion of the project you have proposed. We believe you should be aware of the regulations that apply to joint projects involving the expenditure of NASA funds and, for that purpose, are also sending you a copy of a NASA booklet entitled "Guide to Policies and Procedures for Sponsored Research" which we believe you will find informative and helpful.

The successful completion of the concept which you have proposed would depend upon the verification of a number of unsubstantiated assertions that are made in your presentation, and there is, of course no certainty that such confirmation could be established. This is an additional and important reason for deferring consideration of your concept. Although we cannot make a favorable recommendation in response to your proposal, we do want to thank you for permitting us to examine its contents, and to express our appreciation for your interest in contributing to the advancement of NASA's future program.

(signed)
Francis W. Kemmett
Director of the Staff
Inventions and Contributions Board